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Experimental test of epoxy resin as a radome for patch antennas

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Abstract

In this paper, experimental tests are realized in order to probe the feasibility of the epoxy resin use as patch antenna radome. The interest in this material is due to its low cost and availability, two desirable characteristics for the prototypes fabrication.
At first, it is analyzed the effect of three pieces of epoxy resin of different colors as interference objects between a receiver and a transmitter antenna, that means, their effect on the electromagnetic wave propagation. After, the measurements of S21 parameter were realized considering patch antennas with and without radome made of epoxy resin, in order to analyze the effect of the radome on the antenna performance.
The obtained results allow us to confirm the feasibility of this material to cover the patch antenna, in order to protect them especially from the oxidation produced by the environment. Additionally, the use of colorant hides the antenna geometry to the user, which is desiderating for commercial purposes.

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1. Introduction

Today, antennas are an important part of wireless systems. They are widely used in microwave and millimeter wave applications, because their advantages such as low profile, light weight, and so on. Diverse geometries and arrays to design patch antennas can be found in a great amount of references. However, the analysis of the effect of the radome on the performance of the antenna patch is not so widely analyzed, in particular about the materials used for this purpose. Radomes are used to protect antennas of the environment hazards, and in the case of the patch antennas made of FR-4 (Flame-Retardant-4) specially, of the oxidation of the radiant patch and the ground plane made of copper. Patch antennas are used for indoor and outdoor applications; in both cases the oxidation can be produced.

In [1], the effect of a radome of triangular patch antenna on resonant frequency is studied thoroughly, using a very simple and accurate CAD model to predict the effect of superstrate on resonant frequencies of an ETPA (Equilateral Triangular Patch Antenna).

Another case is presented in [2], where an air-layered patch antenna incorporated with metamaterial superstrate structure is presented. According to the measured result, the metamaterial antenna radome can improve the antenna gain to about 2.0 dB in WiMAX 3.5 GHz band.

A study for estimating the resonant frequency of a multilayered triangular patch with a simple closed form expression was proposed in [3]. The computed values for different substrate-superstrate combinations were also compared with full wave spectral domain analysis.

In a technical document of Amotech Co. [4], it is mentioned that a microstrip patch antenna placed in a plastic enclosure can have a resonant frequency shifted downward by several MHz, depending on the following characteristics of the radome:

- Thickness.
- Dielectric constant.
- Distance between the antenna front face and the inner radome face.

But, a relationship between shifts of resonant frequency and the features of the radome is absent.

Other technical document [5] recommends the following materials for their use as enclosure for patch antennas:

- ABS plastic.
- Teflon.
- Polypropylene.
- Polystyrene.
- Polycarbonate.

However, sometimes these materials are difficult to obtain. In the prototype fabrication process, it is desired to account with materials of low cost or retail purchases at low prices, and also available in the market.

In this work, we use epoxy resin as a radome and present several experimental test, in order to observe at first the effect of this material on the electromagnetic wave propagation, and after, its effects when it is used as radome on the antenna performance. These tests are necessary because we do not have accurate electric and electromagnetic information of the resin epoxy used, which is necessary to carry out the corresponding simulations of both situations.

For example, in the bibliography, two values for the dielectric permittivity of the epoxy resin in intrinsic state, ε_r of 3.1 [6] and of 4.2 were found [7]. Additionally, liquid colorants were diluted in the epoxy resin in order to hide the geometry of the antenna to the user, which is desirable for commercialization purposes.

This paper is organized as follows: In section 2, the experimental set up to probe the interference of the material and to analyze the transmission-reception process is presented. In section 3, the test of interference of epoxy resin of different colors is carried out. In section 4, the analysis of the repeatability fabrication and assembling process is carried out for the antenna without radome. In section 5, the tests of the antenna performance with and without radome are shown; and finally, some concluding remarks are presented in section 6.

Nomenclature

Rx	Reception antenna
Tx	Transmission antenna
A1	Antenna 1
A2	Antenna 2
A3	Antenna 3
A4	Antenna 4
A5	Antenna 5

2. Experimental set up

The first step was to design the experimental set up shown in Fig. 1, with the laboratory equipment. The experimental set up is a simple arrangement with two antennas: one of them was used for transmit the signal from a synthesized signal generator (Agilent 83732B), and the other one was used to receive the signal in the spectrum analyzer (Agilent 8563EC) (Fig. 2). The distance between them was established at 6 cm (Fig. 3). The antennas used in experimental tests were presented in [8], designed at 2.4 GHz on FR-4, with sizes 4.912 cm x 4.016 cm, and a thickness of 1.6 mm. With this simple set up we obtain the experimental parameter S21 (transmission coefficient) and analyze the effects of the epoxy resin.

Besides of the experimental set up, it was necessary to fabricate several pieces of epoxy resin. Three piece of epoxy resin with different colors were fabricated, in order to analyze their effect on the parameter S21 due to interference. In Fig. 4, the three pieces of epoxy resin (blue, red and transparent), with a thickness of 1 cm is presented. Colors were chosen because red and blue are extremes of the visible spectrum. It is well-known that the wavelength of blue is 0.5 μm, and of red is 0.66 μm.

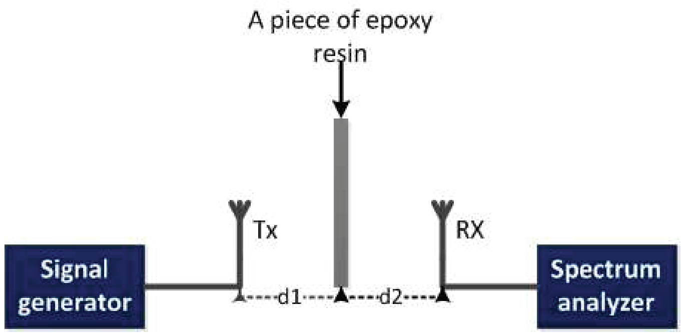


Fig. 1. Experimental setup scheme.

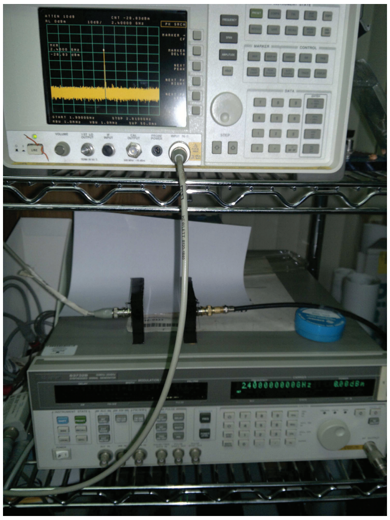


Fig. 2. Experimental set up with the signal generator and the spectrum analyzer.

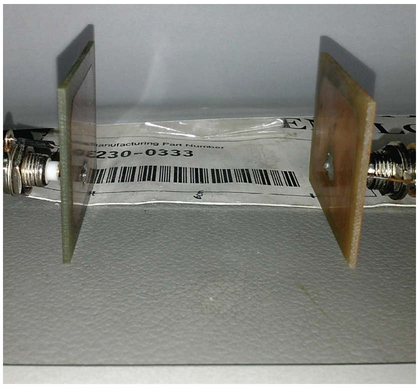


Fig. 3. Wireless system with a distance of 6 cm between two antennas under tests.

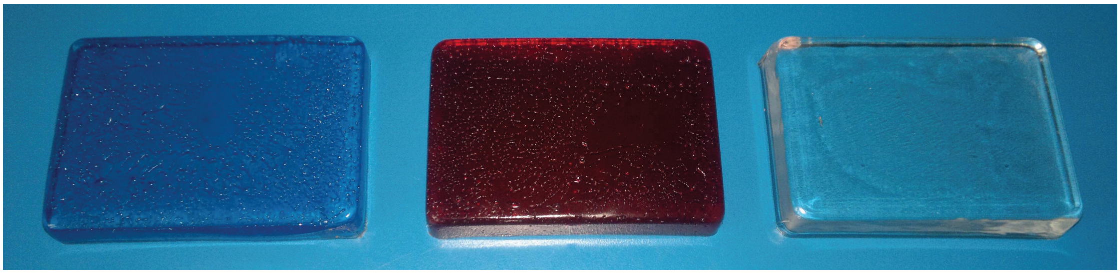


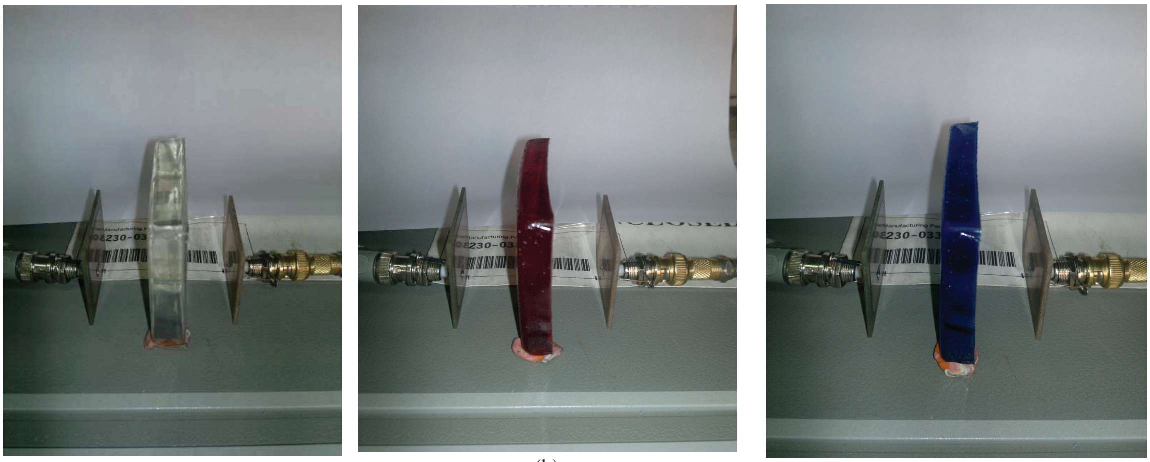
Fig. 4. Rectangular pieces of epoxy resin with color (from left to right: blue, red and transparent).

3. Tests of interference produced by epoxy resin

At first, we used the three pieces of epoxy resin to analyze the effects in the wireless systems proposed in section 2. The piece of epoxy resin was located at the middle of the distance between the two antennas considered in section 2 between both antennas, as shows in the Fig. 5.

The frequency sweep was realized from 2 to 2.8 GHz with steps of 0.5 GHz.

Fig. 6 shows the measured parameter S21 (from 2 to 2.8 GHz.) for the four cases: with transparent, with red, and with blue epoxy resin, respectively; and without epoxy resin is also shown. The numerical analysis is presented in Table 1.



(a) (b) (c)

Fig. 5. Experimental test with a piece of epoxy resin between two patch antennas: (a) transparent, (b) red, and (c) blue.

Table 1. Numerical analysis of the parameter S21 of the material test.

	Transmission coefficient data between Antennas with resin interference	Transmission coefficient data between the average data of antennas with resin interference and without it
Average standard deviation	0.2986	1.2947
Minimum standard deviation	0.0000	0.2500
Maximum standard deviation	0.9826	4.4150
Average variance	0.1515	3.4521
Minimum variance	0.0000	0.0625
Maximum variance	0.9656	19.4922

As it can be observed in figure 6, the standard deviation and variance of transmission data of the antennas with resin interference are small, confirming that the color does not influence the resin effect. But the effect of the resin on the transmission notably increases the response for frequencies bigger than the operation frequency producing a bigger value of variance.

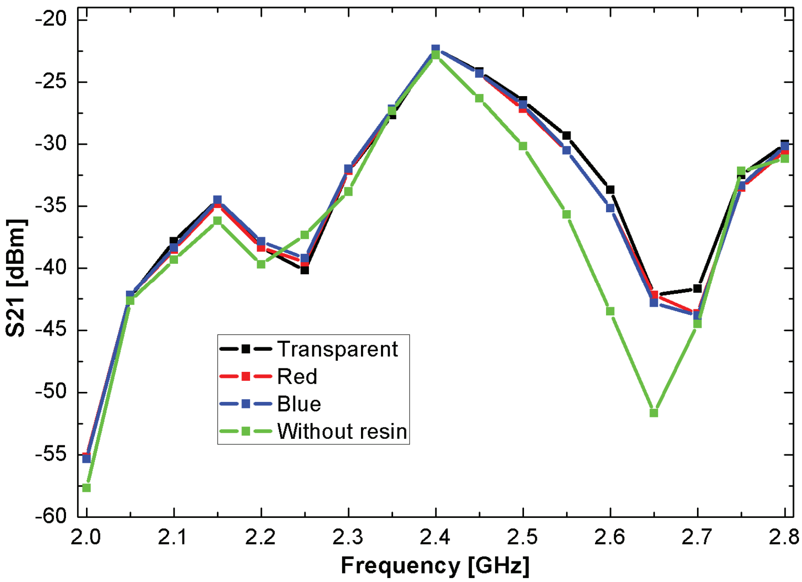
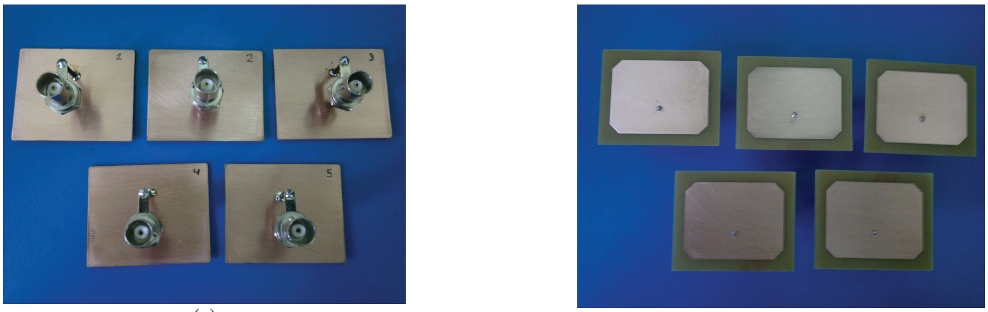


Fig. 6. Parameter S21 of the material test.

4. Tests of antenna fabrication repeatability

It was necessary to check the repeatability of the prototypes fabrication and assembling processes, before to encapsulate them with epoxy resin. In Fig. 7 there are shown five prototypes of the patch antenna, which were fabricated in the Microwave laboratory with the ProtoMat S42 machine.

Using the experimental set up shown in section 2, the parameter S21 was measured for each antenna. (Fig. 8), considering it as a receiver antenna and the other ones as transmitter antennas, replacing them for each measurement.



(a) (b)

Fig. 7. Views of the prototypes of the patch antenna: (a) rear and (b) front.

In all of graphs of Fig. 8, a similar performance of all antennas under test is observed. There are small differences as it happens in all fabrication processes, as it is well-known that two physical devices are different generally due to inhomogeneities in the substrate or to the precision of fabrication the process. Although these differences, we can observe that the operation frequency is the same in all cases. The differences in the S21 parameter show that the differences are acceptable, the maximum standard deviation was of 1.0473 and the minimum was of 0.6783 (table 2).

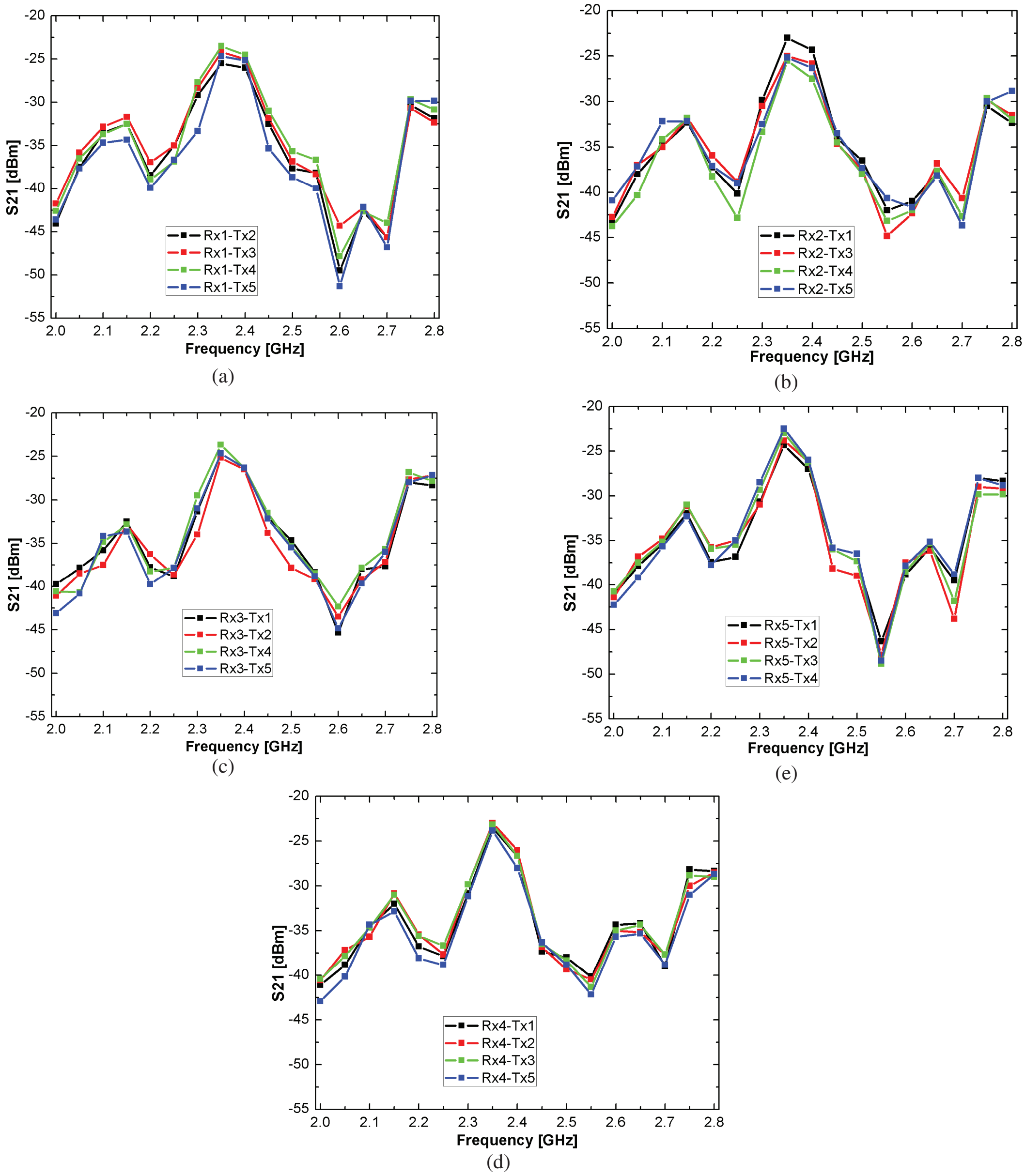


Fig. 8. Parameter S21 with the antenna (a) 1, (b) 2, (c) 3, (d) 4 and (e) 5 as receiver.

Table 2. Numerical analysis of the S21 parameter with antennas 1, 2, 3, 4 and 5 as receiver, respectively.

	Antenna 1	Antenna 2	Antenna 3	Antenna 4	Antenna 5
Average standard deviation	1.0473	0.9417	0.8419	0.6783	0.7675
Minimum standard deviation	0.2500	0.2160	0.0736	0.2447	0.3023
Maximum standard deviation	2.5771	1.6015	1.6217	1.1301	1.9784
Average variance	1.4361	1.0757	0.8900	0.5310	0.7268
Minimum variance	0.0625	0.0467	0.0054	0.0599	0.0914
Maximum variance	6.6417	2.5649	2.6298	1.2772	3.9142

It can be observed that the repeatability of the fabrication process shows a considerably small standard deviation, but a bigger variance especially for smaller and bigger frequencies than the operation frequency.

5. Test of antenna performance with radome

Finally, two tests with only two pairs of antennas encapsulated in epoxy resin were realized. With each pair, one of them was used at first as transmitting antenna and the other one as receiving antenna, with and without radome. After, the antennas were interchanged; the transmitting was used as the receiving antenna and vice versa. Characteristics of the radomes are:

- For antennas 1 and 2:
  - Amount of resin: 60 g.
  - Colorant: 50% red and 50% blue.
  - Depth the antenna on the package: 5 mm.
  - Total thickness of the radome: 1.1 cm.
- For antennas 3 and 4:
  - Amount of resin: 60 g.
  - Colorant: 100% red.
  - Depth the antenna on the package: 10 mm.
  - Total thickness of the radome: 1.3 cm.

The difference in the radome thickness was chosen in order to observe the effect of this characteristic on the transmission coefficient.

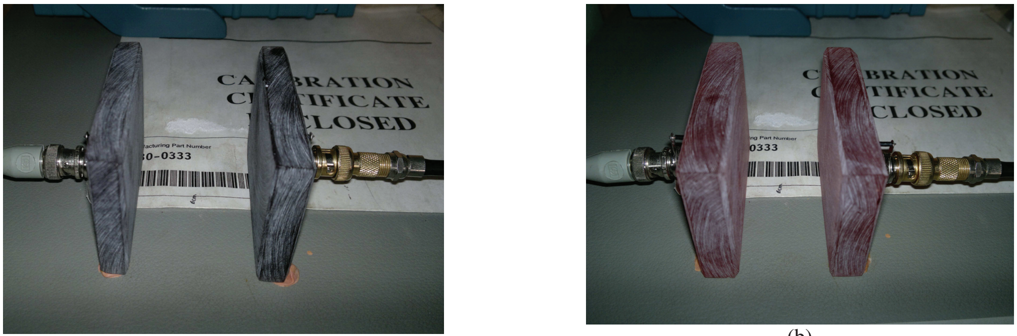
In Fig. 9, the two pairs of the antennas with radome are shown. The separation between them in the experimental design is again 6 cm, no matter the radome of epoxy resin, which were polished to avoid surface effects.

The average of S21 parameters obtained with antennas with and without radomes are present in the Fig. 10, where we can observe that the deeper encapsulated antenna corresponds to the wider bandwidth. The smaller housing shows an increment in the S21 parameter before the operation frequency, but with an enough bandwidth to support the antenna performance.

From these results, it can be suggested to use radomes of at least 1 cm of depth.

There is a lightly shift downwards the resonance frequency as it was mentioned in [4], produced by the complete response due to the resin effect over the antenna response without radome. The transmission coefficient has bigger values for the antennas with radome as it was expected.

The effect of the radome on the antenna performance is similar for frequencies bigger than the operation frequency as it happens for the analysis of interference of the resin shown in section 3. For smaller frequencies the behavior can be attributed to the resin effect and to the variance observed due to the repeatability of the fabrication process shown in section 4.



(a) (b)

Fig. 9. (a) Antennas 1 and 2 with encapsulated, and (b) antennas 3 and 4 with encapsulated.

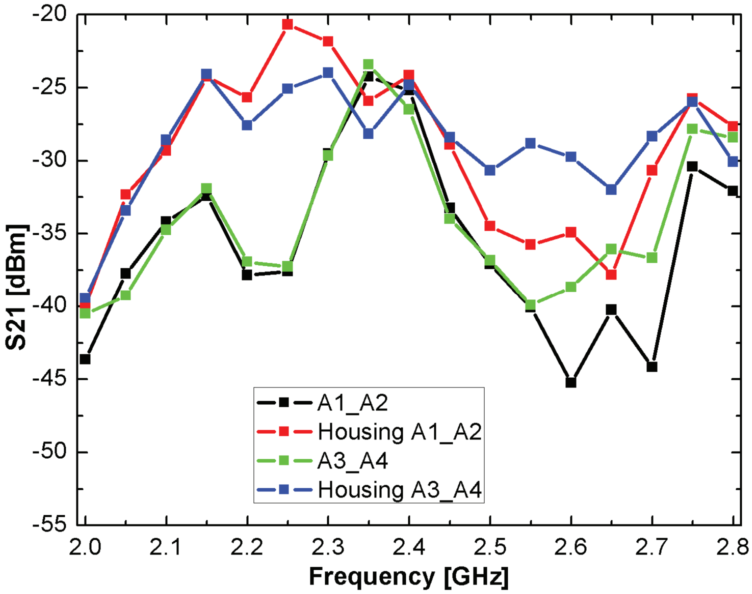


Fig. 10. Parameters S21 of the antennas 1, 2, 3 and 4 with encapsulated and without the same.

6. Conclusions

It has been demonstrated that the epoxy resin can be used as a radome of a patch antenna without to affect its performance severely. However, it is necessary to realize more tests considering different depth of encapsulated in order to choose the most appropriate.

The color does not affect the performance of the patch antenna with radome made of epoxy resin. This material can be used for commercial purposes, because it hides the antenna geometry to the user.

In the practical tests the encapsulated influence was observed in the following characteristics:

- There is a little shift downward the operating frequency.
- There is an increment in the bandwidth.
- The parameter S21 has lightly bigger values with the antenna radome than without it.

Therefore, the epoxy resin radome not only protects the patch antenna to the environment hazards, it also lightly improves the antenna performance.

Additionally, the epoxy resin has low-cost and availability, making it an acceptable material for its use as patch antenna radome.

Acknowledgements

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